

The University of Chicago

BOULDERS FROM BENGALIA

A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR
OF PHILOSOPHY

DEPARTMENT OF GEOLOGY AND PALEONTOLOGY

1935

By
WILLIAM BALTZER KRAMER III

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ABSTRACT

This paper treats of the boulders in the Carboniferous Caney shale in the Ouachita Mountains of southeastern Oklahoma. Some of the boulders are composed of local rock, but others are composed of rock which does not crop out in the Ouachitas. As theories of long-distance transportation of the so-called exotics are considered inadequate, a theory is developed which explains the origin of the boulders from a local source.

Evidence is cited which indicates that rocks like those which comprise the apparently foreign boulders underlie certain areas in the Oklahoma Ouachitas. A land, Bengalia, existed along the north side of the Ouachita area throughout most of Paleozoic time. Crustal warpings caused variations in the positions of land and sea areas, and erosion exposed the older rocks. During most of Mississippian time, Bengalia formed the north barrier of the filter-basin-like Ouachita trough in which the thick Stanley and Jackfork formations were deposited while only a few hundred feet of lower Caney shale were being laid down to the north and west. By later Caney time, Bengalia and Llanoria, the land to the south, were both lower, and straits connected the trough with seas to the north and west. Earth tremors, accompanying downwarping of the trough, caused submarine landslips of boulders from Bengalia into the upper Caney shale then being deposited in the northwest side of the trough.

INTRODUCTION

The problem of the boulders in the Caney shale and adjacent formations of the Ouachita Mountains in Oklahoma has been studied for more than a quarter of a century, and because of its spectacular and baffling nature it has attracted many geologists.

The "Caney" boulders are composed of sedimentary rocks older than the matrices in the respective horizons. As many of them are of rock which does not crop out in the Ouachitas, they have been called exotic. Some of the boulders or blocks are so immense that their transportation from an extra-Ouachita source is doubtful.

The summer of 1930 was spent in the Oklahoma Ouachitas studying the geology of the region with special reference to the boulder problem. Most of the known outcrops of boulder horizons were visited.¹

¹ The writer wishes to express his appreciation for hospitality shown him by many residents of the region. Thanks are especially due to Mr. Lee Basket of Johns Valley, Mr. Bill Epperly of Bengal, and Mr. Alfred L. Allen of Ti, for helpful guidance in areas near their homes. Mr. H. D. Miser gave several much appreciated suggestions regarding field study. The writer is especially indebted to Professor R. T. Chamberlin and to Dr. Carey Croneis of the Department of Geology at the University of Chicago for many helpful suggestions and criticisms.

PREVIOUS INVESTIGATIONS

The first-discovered "Caney" boulders were thought to be remnants of a limestone ledge, and Taff² mapped the underlying Jackfork sandstone and Stanley shale as Ordovician, because fossils of that age were found in some of the blocks. Evidence of the post-Ordovician age of these formations, however, was soon obtained.³ Further study of the occurrence of the boulders showed that they were neither intra-formational nor basal conglomerate fragments. Taff⁴ briefly described the boulder horizons, and Woodworth⁵ described the outcrop at Compton cut near Talihina, and concluded that scratches found on boulders at that locality are of tectonic rather than of glacial origin. More recently Miser,⁶ Ulrich,⁷ Powers,⁸ and van der Gracht⁹ have given more complete accounts of the age, occurrence, and possible origin of the boulders.

STRATIGRAPHY OF THE OUACHITAS

The rocks exposed in the Ouachita Mountains are almost entirely non-limestone sedimentary¹⁰ rocks of Paleozoic age. All systems from Cambrian to Pennsylvanian are at least partially represented. The total thickness of strata is about 25,000 feet of which 15,000–20,000 feet are of Carboniferous age.¹¹ Sandstone and shale forma-

² J. A. Taff, *U.S. Geol. Surv., Geol. Atlas, Atoka Folio, No. 79* (1902).

³ E. O. Ulrich, "Fossiliferous Boulders in the Ouachita Caney Shale and the Age of the Shale Containing Them," *Okla. Geol. Surv. Bull.* 45 (1927), p. 5.

⁴ "Ice-borne Boulder Deposits in Mid-Carboniferous Marine Shales," *Geol. Soc. Amer. Bull.*, Vol. XX (1909), pp. 701–2.

⁵ J. B. Woodworth, "Boulder Beds of the Caney Shale at Talihina, Oklahoma," *Geol. Soc. Amer. Bull.*, Vol. XXIII (1912), pp. 457–62.

⁶ H. D. Miser, "Structure of the Ouachita Mountains of Oklahoma and Arkansas," *Okla. Geol. Surv. Bull.* 50 (1929), pp. 27–30.

⁷ *Op. cit.*

⁸ Sidney Powers, "Age of the Folding of the Oklahoma Mountains," *Geol. Soc. Amer. Bull.*, Vol. XXXIX (1928), pp. 1031–72.

⁹ W. A. J. M. van der Gracht, "The pre-Carboniferous Exotic Boulders in the So-called Caney Shale in the Northwestern Front of the Ouachita Mountains of Oklahoma," *Jour. Geol.*, Vol. XXXIX (1931), pp. 697–715.

¹⁰ Several small outcrops of igneous rocks ranging in age from possible Ordovician to Upper Cretaceous occur in the Arkansas and McCurtain County, Oklahoma, areas.

¹¹ H. D. Miser and C. W. Honess, "Age Relations of the Carboniferous Rocks of the Ouachita Mountains of Oklahoma and Arkansas," *Okla. Geol. Surv. Bull.* 44, p. 7.

tions of Cambrian and early Ordovician age are confined in outcrop to Arkansas and McCurtain County in the southeast corner of Oklahoma. The remaining rocks of the older Paleozoic and Devonian systems are mostly shales and unusually thick, bedded flints and cherts which have a wide distribution in Arkansas and McCurtain County, Oklahoma. These beds also crop out in the Potato Hills, in the north-central part of the Oklahoma Ouachitas, and in Black Knob Ridge at the west end of the province, where they are known as the Stringtown shale (Ordovician) and Talihina chert (Ordovician to Mississippian²). Arkansas novaculite (Devonian to Mississippian), which is equivalent to upper Talihina chert, also crops out in five other small inliers on the north-northwest side of the Oklahoma Ouachitas. The Blaylock sandstone (Silurian) is confined in outcrop to McCurtain County, Oklahoma, and to Arkansas. Much of Silurian time appears to be represented by hiatuses.

The Hot Springs sandstone which is present in the eastern end of the mountains in Arkansas, and the thick Stanley shale (0-10,000 feet) are of Carboniferous age, and unconformably overlie the older rocks. The thick Jackfork sandstone (0-6,600 feet) conformably overlies the Stanley shale. The Stanley shale and Jackfork sandstone have the most widespread exposures of any formations in the Ouachita Mountains, but they are not present along the north side of the province in Oklahoma.

The Caney black to gray shale is the next younger Carboniferous formation, and is exposed along the north side of the mountains in Oklahoma. Along the northern border of the province the formation lies on the Arkansas novaculite, part of which is the equivalent of the Woodford chert, and the Stanley and Jackfork formations are not present. This stratigraphic relation of the Caney shale to older rocks, which is the same in the Arbuckle Mountains about 15 miles to the west of the Ouachitas, is shown in two small areas along the northwest arc of the mountains. At the Wesley inlier the sequence is Arkansas novaculite, Caney, Wapanucka,¹² and Atoka, but, at the Brushy Creek inlier, which is 8 miles northeast of Wesley, the Wapanucka has not been recognized. At Brushy Creek there are cherty limestone beds which are not the equivalent of any rocks in the Ar-

¹² Powers, *op. cit.*, p. 1042.

buckle Mountain section, but which are the equivalent of the lower division of the Arkansas novaculite, and there are overlying beds which correspond to younger portions of that formation. The absence of the Stanley and Jackfork formations along the north side of the mountains farther to the east is also shown at two localities near Bengal, at which the Atoka formation rests on Arkansas novaculite. Here the Caney and Wapanucka formations, as well as the Stanley and Jackfork, are missing. This relation also appears to exist at another small inlier of novaculite on the northwest arc, 7 miles south of Hartshorne.

Farther south, but in the north half of the Oklahoma Ouachitas and near their west end, a black shale conformably overlies the Jackfork sandstone. The age of this shale is a matter of controversy. Most geologists who have published opinions on the subject believe that this shale is the Caney. In fact, the type locality of the Caney shale which is Johns Valley, formerly called Caney Basin or Cove,¹³ is in this region where the black shale overlies Jackfork sandstone. From the lower part of the black shale in Johns Valley, Miser¹⁴ has collected a fauna, all of the fossils of which "belong to the fauna of the Mississippian Caney shale." This fauna was found in phosphate nodules and "concretionary masses of limestone." The criteria for distinguishing between concretionary masses of limestone and exotic blocks and boulders of older rock appear to be (1) that the concretions lie parallel to the bedding, (2) that the lithology of the shale including the character and distribution of nodules and limestone concretions is the same as in the Caney where it rests on Woodford, and (3) that at the localities of the collection all the fossils and rock are of Caney age. Miser believes that the fauna is indigenous, and that the shale which lies on the Jackfork is Caney shale and contains beds of both Mississippian and Pennsylvanian age.¹⁵ Ulrich,¹⁶ however, believes that Miser's fauna is not indigenous, but that it was transported into the shale, and that the shale which lies on the Jackfork has no known fauna or flora of its own. He has proposed the name, "Johns Valley shale," for the black shale overlying Jackfork sandstone, and refers both of these formations to the Lower Penn-

¹³ Miser and Honess, *op. cit.*, p. 11.

¹⁴ *Ibid.*, footnotes on pp. 22 and 23.

¹⁵ *Ibid.*, p. 28.

¹⁶ *Op. cit.*, p. 23.

sylvanian, because of the few, not very diagnostic, fossils from the Jackfork, and because a formation of coarse clastic material is such a one as might be expected to be the initial formation of a system.

The Wapanucka limestone overlies the Caney shale along the north border of the Ouachitas in Oklahoma and in the Arbuckle Mountains. This formation contains such a definitely very early Pennsylvanian fauna that, on this evidence alone,¹⁷ it may be thought that the 6,000-7,000 feet of Jackfork sandstone which underlies a sandstone bed containing this fauna in northwestern McCurtain County, Oklahoma,¹⁸ cannot also be of Pennsylvanian age. Wapanucka limestone crops out on Windingstair Mountain¹⁹ near Bengal, several miles south of the north border of the mountains, where the succession is Jackfork, Caney, and Wapanucka. Limestone of probable Wapanucka age was also found on the north slope of Windingstair Mountain at a new locality at Bill Epperly's prospect $2\frac{1}{2}$ miles east of Bengal (S. $\frac{1}{2}$ Sec. 8, T. 4 N., R. 22 E.). Wapanucka strata have not been reported from the interior of the mountains except at the Bengal and McCurtain County localities.

Succeedingly younger Pennsylvanian formations are the Atoka sandstone and shale formation, the Hartshorne sandstone, the McAlester shale, the Savanna sandstone, and the Boggy shale. These formations crop out along the north and northwest border of the Ouachita Mountains, in the Arkansas Valley, and on the east end of the Arbuckles. The Boggy shale is the youngest formation which is definitely known to have been folded with the Ouachita Mountains. Sandstone and shale strata preserved in synclines in the interior of the western end of the Ouachitas overlie Caney shale, and have been referred to the Atoka. Wapanucka beds have not been recognized in these synclines, the easternmost of which is Johns Valley. In the Buktukola syncline in northwestern McCurtain County several thousand feet of sandstone beds overlie the Jackfork sandstone. The sandstone above the Jackfork is thought to be Atoka,²⁰ because a

¹⁷ Carey Croneis, "Pennsylvanian Overlap," *Amer. Assoc. Petr. Geol. Bull.*, Vol. XV (1931), pp. 471-73.

¹⁸ C. W. Honess, "Geology of Southern Leflore and Northwestern McCurtain Counties, Oklahoma," *Bur. Geol. Cir. 3* (Norman, Okla., 1924).

¹⁹ Powers, *op. cit.*, p. 1043.

²⁰ Miser and Honess, *op. cit.*, p. 21.

thin sandstone containing a Wapanucka fauna²¹ intervenes between the two formations. There is no evidence of interruption in sedimentation, and, accordingly, the Caney formation is probably represented by sandstone strata in the upper part of the Jackfork. The Atoka overlies the Jackfork in two synclines extending east-west across Clark and Pike counties, along the south border of the Ouachitas in Arkansas. Atoka also overlies Jackfork along the north side of the Arkansas Ouachitas and in the Arkansas Valley in Arkansas, the Caney shale being essentially absent. Younger rocks than the Atoka have not been recognized in the interior of the Ouachitas.

DISTRIBUTION OF BOULDERS

Boulders and blocks of rock in Caney shale and adjacent formations are confined in outcrop to the north side and the west end of the Oklahoma Ouachitas. Fragments of limestone in a Wapanucka breccia, described by Wallis²² from the east end of the Arbuckles, have only pebble dimensions (1 mm.—3 cm.). Most of the boulder horizons are in the southernmost outcrops of "Caney," presumably where the formation lies on Jackfork. At the west end of the mountains there are boulder horizons in Caney on Jackfork. There are, however, three boulder localities in that part of the "Caney" which probably does not overlie Jackfork, but which overlaps the Arkansas novaculite. Two localities are south of Recyl (Sec. 25, T. 4 N., R. 17 E.,²³ and a new locality, Sec. 11, T. 3 N., R. 17 E.), and the third is 8 miles east of Bengal²⁴ (on section line between Sec. 7 and 8, T. 4 N., R. 23 E.). Boulder horizons crop out from about 10 miles east of Atoka eastward to the vicinity of Boles, Arkansas, about 20 miles east of the Oklahoma border.

Boulder horizons may be grouped into two quite general stratigraphic ranges. The lowest is about 5–10 feet²⁵ above the base of the Caney or possibly in the top of the Jackfork, as in Johns Valley (below Miser's Mississippian Caney fauna) and near the top of the

²¹ *Ibid.*, p. 14.

²² B. F. Wallis, "The Geology and Economic Value of the Wapanucka Limestone of Oklahoma," *Okla. Geol. Surv. Bull.*, XXIII (1915), p. 72.

²³ Powers, *op. cit.*, p. 1041.

²⁴ Ulrich, *op. cit.*, p. 11, locality No. 27.

²⁵ Powers, *op. cit.*, p. 1043.

Jackfork north of Compton cut.²⁶ The other horizons are in Pennsylvanian rocks in the upper Caney (Springer), in Wapanucka²⁷ shale, and in the Atoka at Stapp.

Boulders are embedded in black or gray shale matrices, and in a sandstone matrix in the Atoka horizon at Stapp. Because of these matrices the beds do not resemble friction or fault surface breccias. Boulders are subangular and rounded, and many are corroded. They are arranged in beds in the shale at some localities and boulders of several different kinds of rocks commonly occur in the same bed.

ARBUCKLE SECTION COMPARED WITH ROCKS IN THE BOULDERS

The east end of the Arbuckle Mountains lies only a few miles west of the Ouachitas, but the Paleozoic rocks there exposed are very different from those which crop out in the Ouachitas, and yet Arbuckle-like rocks have largely contributed to the Caney boulders. Ulrich²⁸ has studied faunas found in the boulders, and conclusions respecting their identity are taken from his paper.

Paleozoic rocks overlies a pre-Cambrian basement of Tishomingo granite at the east end of the Arbuckles. Pre-Cambrian and Cambrian rocks are not represented in Ouachita boulders, and in Ulrich's collection only three fossils taken from boulders represent the upper part (Canadian) of the Arbuckle (Cambro-Ordovician) limestone. With the exception of McCurtain County, nowhere in the Oklahoma Ouachitas do rocks of Arbuckle or greater age crop out.

The Simpson-Bromide sandstone, shale, and limestone formation and the younger Viola limestone unconformably succeed the Arbuckle limestone in the Arbuckle Mountains. These formations are of Middle and Upper Ordovician age. Rocks representing this time interval in the Ouachitas are the Stringtown or Womble shale, the Bigfork chert, and the Polk Creek shale. Numerous fossiliferous boulders of Middle and Upper Ordovician age have been found in the Ouachita "Caney," and many of the fossils are identical with those from the Simpson, Bromide, and Viola, but about one-fifth of the species have not been found in place in the Arbuckles, and a Lower Simpson fauna has not been found.²⁹ A single boulder is referred to

²⁶ *Ibid.*

²⁷ *Ibid.*

²⁸ Ulrich, *op. cit.*, pp. 12-21.

²⁹ *Ibid.*, p. 16.

the Sylvan shale. Rocks in Ordovician boulders are more like Arbuckle rocks than they are like outcropping Ouachita rocks, but they differ somewhat from the former.

Taff's³⁰ Hunton formation in the Arbuckles has been divided by Reeds³¹ into five formations: the Chimneyhill limestone and Henryhouse shale of Silurian age, and the Haragan shale, Bois d'Arc limestone, and Frisco limestone of Lower Devonian age. Very much of Hunton time appears to be represented by hiatuses in the Ouachita section in Oklahoma which is exposed in the Potato Hills and Black Knob Ridge. The upper part of the Talihina chert in these two inliers includes the Missouri Mountain slate and the lower, middle, and upper Arkansas novaculite. The slate may partially represent the Devonian portion of the Hunton. Oölitic limestone boulders of Chimneyhill (Silurian) age were found at two widely separated localities. Chimneyhill time is represented by a hiatus in the Talihina chert.

Devonian fossils were found in chert blocks from two localities. The rock is distinctly Ouachita rock³² and is referred to the Arkansas novaculite which crops out in the Brushy Creek inlier 12 miles northwest of the most fossiliferous of the boulders, which was found in Johns Valley. Arkansas novaculite crops out $\frac{1}{2}$ mile and $1\frac{1}{2}$ miles west of Bengal, and the writer was fortunate in finding a new outcrop of the formation (center of N. $\frac{1}{2}$ of N. $\frac{1}{2}$ of Sec. 7, T. 4 N., R. 21 E.) $4\frac{1}{2}$ miles west of Bengal. At the latter locality limestone and shale beds as well as black chert are exposed, but no identifiable fossils were found. This outcrop is within 5 miles to the northeast of Ulrich's other Devonian boulder locality.

Many Mississippian Caney fossils have been found in the Caney shale of the interior Ouachitas. Some of the large shells are silicified and are not in a like matrix. They may have entered the shale as did the boulders, thus being boulders themselves. If Miser's contention, however, that there are Mississippian Caney beds in Johns Valley is correct, these fossils or "boulders" are probably of Ouachita rock.

From three localities, two near Bengal and one near Stapp, Pennsylvanian Wapanucka boulders are reported. Powers³³ has shown

³⁰ *Op. cit.*

³¹ C. A. Reeds, "The Arbuckle Mountains, Oklahoma," *Okla. Geol. Surv. Cir.* 14 (1927), p. 12.

³² Ulrich, *op. cit.*, p. 19.

³³ *Op. cit.*

that there are boulder horizons definitely younger than Wapanucka within a few miles of each of these horizons and doubtless the boulders came from such horizons. Miser³⁴ and the writer have found outcrops of Wapanucka limestone on Windingstair Mountain near Bengal. In the railroad cut 1 mile south of Stapp a boulder horizon is referred to the Atoka formation,³⁵ because it has a sandstone matrix. In this sandstone bed, boulders or blocks of black shale containing nodules were found by the writer. The shale fragments were several inches in diameter and undoubtedly are Caney shale.

There are many boulders which contain no fossils, and consequently cannot be definitely placed in the section. Chert and flint boulders are abundant although of relatively small sizes, probably because the rock is friable. All of the Talihina horizons of chert may be represented, including Bigfork chert and Arkansas novaculite. These chert boulders are of Ouachita rocks. There are also many sandstone, quartzite, and shale boulders, but they are neither so conspicuous nor so numerous as limestone and flint boulders.

The thick Stanley-Jackfork sequence is absent in the Arbuckles. This time interval may be represented by a hiatus, or perhaps it is more likely, as suggested by Honess,³⁶ that Caney shale in the Arbuckles and along the north border of the Ouachitas represents Stanley and Jackfork, as well as the Caney of the interior of the Ouachitas.

In summing up the characteristics of the rocks comprising the boulders, it should be noted that the younger Paleozoic systems are represented by Ouachita rocks which crop out in small areas along the north and northwest border of the mountains. The older Paleozoics are conspicuously represented by Ordovician limestones, and there are a few boulders of Chimneyhill (Silurian) limestone. The immense blocks in Johns Valley are probably of Ordovician age.³⁷ Boulders of lower Paleozoic rocks are more like the Arbuckle rocks than the outcropping Ouachita rocks, but not nearly all of the fossiliferous limestone formations of the Arbuckles are represented.

³⁴ In Powers, *op. cit.*, p. 1043.

³⁵ *Ibid.*, p. 1041.

³⁶ C. W. Honess in Miser and Honess, *op. cit.*, p. 11.

³⁷ Powers, *op. cit.*, p. 1043.

THEORIES OF ORIGIN OF THE BOULDER BEDS

Because of the apparently foreign rocks comprising some of the boulders, various theories have been proposed to explain their introduction into the Ouachita "Caney" shale. Long-distance transportation, whether by rafting or by overthrusting, is usually postulated. The Criner Hills³⁸ area is the nearest known which might have been a land exposing rocks like those in the boulders at the time of their deposition. But the Criner Hills are many miles to the southwest, beyond strata which are of the equivalent age of the boulder horizons, but which contain no boulders.

Floe- or berg-ice rafting appears to be the most generally accepted means of transportation. In Johns Valley, and there alone, immense boulders of more than 30 feet in greatest dimensions are known. Powers³⁹ and Miser⁴⁰ have given measurements of the largest of these great blocks of rock. Miser's dimensions for three blocks are: 200 feet in length, 110 feet by 195 feet, and 50 feet by 369 feet. Each of these three blocks, all found in only the 10 square mile outcrop of Caney in Johns Valley, is twice as large in greatest dimension as any Pleistocene glacial erratic which the writer has found reported from all of North America. Pilot Rock,⁴¹ near Coule City, Washington, one of the largest glacial boulders, has a greatest dimension of less than 100 feet. The Madison boulder in New Hampshire is about 90 feet long and is thought to have traveled about 3 miles.⁴²

The large erratics of the Iowan drift have in the past been used as a criterion in identifying that sheet, but the largest boulder reported from Iowa⁴³ is 50 feet by 40 feet by $11\frac{1}{2}$ feet. There may be no limit to the size of a mass of rock which can be picked up by a sufficiently large glacier, but the crushing and weaving action caused by the variant pressures within the ice during transportation causes an observed decrease in size with distance from the parent ledge.⁴⁴ Similar

³⁸ *Ibid.*, p. 1044.

³⁹ *Ibid.*, p. 1043.

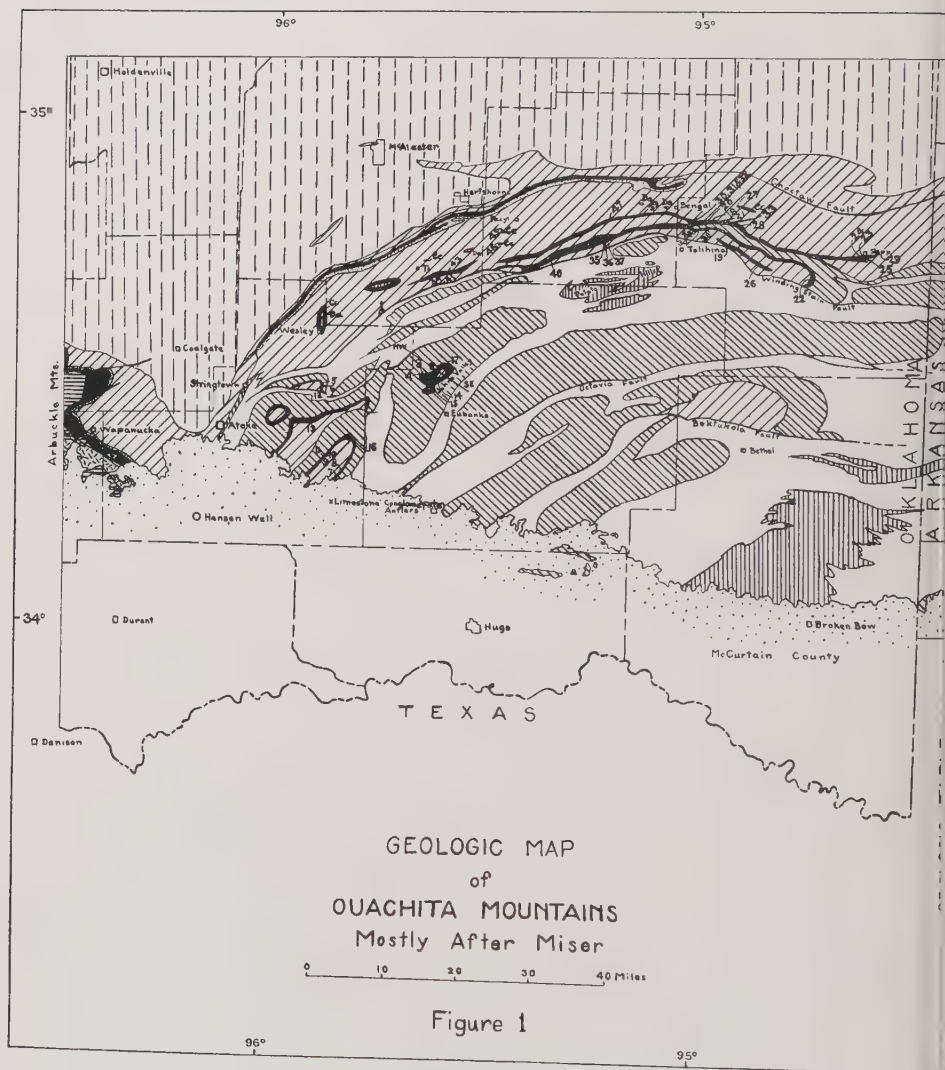
⁴⁰ Miser and Hones, *op. cit.*, p. 22 n.

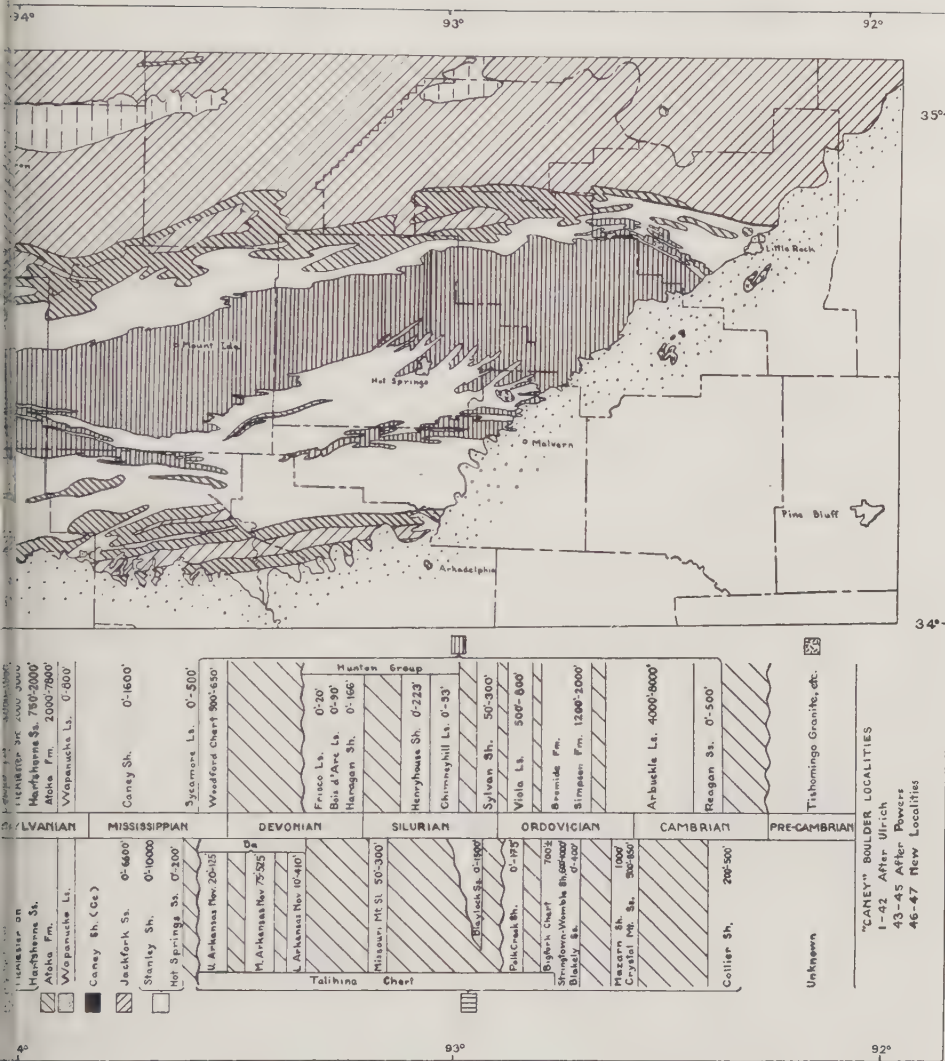
⁴¹ T. C. Chamberlin and R. D. Salisbury, *Geology*, Vol. III (New York, 1907), Fig. 474.

⁴² J. W. Goldthwait, personal communication, May 10, 1931.

⁴³ G. F. Kay, "Some Large Boulders in the Kansan Drift of Southern Iowa," *Ia. Geol. Surv.*, Vol. XXVII (1930), pp. 345-53.

⁴⁴ Goldthwait, *op. cit.*





action in a fault breccia under an overthrust sheet must have an even greater cracking effect. Data at hand regarding the maximum size of Pleistocene glacial erratics indicate that it is highly improbable that three such huge blocks could have been transported into the small Johns Valley area by icebergs from glaciers.

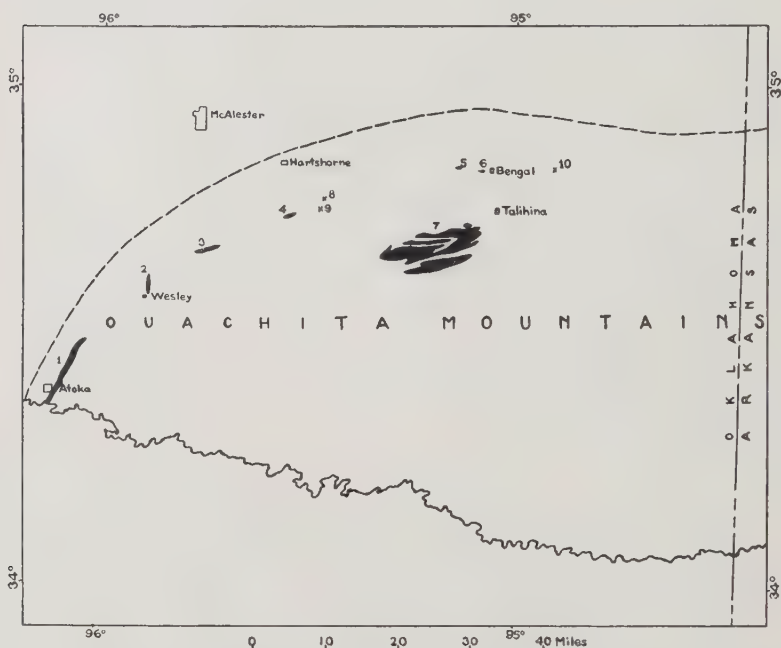


FIG. 2.—Map of southeastern Oklahoma, showing inliers of Bengalia; 1, Black Knob Ridge; 2, Wesley; 3, Brushy Creek; 4, 7 miles south of Hartshorne; 5-6, west of Bengal; 7, Potato Hills, and "Caney" boulder localities along the axis of Bengalia; 8-9, south of Recyl; 10, 8 miles east of Bengal.

Kindle⁴⁵ has stated that "the ability of ice floes to scour the bottom and transport material in shallow arctic seas when driven by currents or the wind is comparable with that of glaciers." Little is known of the ability of floe ice to pick up and carry large masses of rock; for most of such present-day work is confined to the polar regions and deposits from it are under the sea. It is conceivable that

⁴⁵ E. M. Kindle, "Observations on Ice-borne Sediments by the Canadian and Other Arctic Expeditions," *Amer. Jour. Sci.*, 5th ser., Vol. VII (1924), pp. 251-86, 264.

floe ice scouring a cave-pitted limestone coast could enclose and later transport large masses of rock, but it is probably much less competent for this work than would be an ice cap.

Powers'⁴⁶ theory should be especially noted because under it shorter transportation is required. According to him, a land existing in Caney time, on which were exposed the requisite Arbuckle-like rocks, was located in the present site of the Ouachitas, and was much later covered by northward overthrust sheets of Ouachita rocks which had been deposited farther south off the shores of Llanoria. Powers has stated some of the arguments against the theory. Boulders were supposedly derived from the land of Arbuckle-like rocks, but transportation of many miles (at least 10 miles) would have been required to bring them southward into Ouachita deposits.

If floe or berg ice rafts got such masses of rock into them, which seems improbable, and got into open seas, distance of travel is not an important matter, for they might have had clear sailing for many miles before breaking up.

Scratched and grooved "Caney" boulders have been found at a few localities. Compton cut is the best-known locality and the only one known at which scratched boulders are abundant. Woodworth⁴⁷ who has studied this locality has shown rather conclusively that the grooves are of tectonic origin resulting from one boulder grazing another during diastrophism subsequent to the deposition of the boulders in the shale. Scratches on boulders at other localities are probably of the same origin. As the "Caney" shale is an incompetent, abundantly drag-folded formation in the Ouachitas, one may expect to find scratched boulders in many localities where boulders are close together in their horizons.

Powers⁴⁸ and Miser⁴⁹ have considered the possibility of southward overthrusting during Caney time of Arbuckle-like rocks over Ouachita rocks. If the Arbuckle-like rocks were thrust southward in this manner, the gliding planes must have been in the Caney shale, because faults such as those postulated are not known in the older rocks. The blocks and boulders would be erosional remnants of such an overthrust mass. Southward overthrusting is not the direction of

⁴⁶ *Op. cit.*, p. 1044.

⁴⁸ *Op. cit.*, p. 1046.

⁴⁷ *Op. cit.*

⁴⁹ *Op. cit.*, p. 29.

movement which might be expected, if one believes that the later, post-Boggy, diastrophism which folded the Ouachitas was directed from the south. Facts suggesting that the direction of this mountain-making diastrophism was from the south or southeast are: (1) that the folding becomes less intense toward the north, (2) that the folds in the northern part of the mountains are overturned toward the north, and (3) that the northwest arc of the mountains forms a salient projecting toward the northwest. There is considerable doubt of the competency of thin shells of the earth's upper crust to transmit pressures for great distances. In McCurtain County on the south flank of the mountains the folds are overturned toward the south. As much of the south flank of the fold belt is concealed under the coastal plain, this southward overturning is the only recognized evidence indicating that the Ouachitas constitute a wedge-shaped sector which has been folded by compression from both the north and the south, rather than that the mountains were folded by pressure directed only from the southeast. With this view in mind, while reasoning from analogy, it is unsafe to conclude that Arbuckle-like rocks which were deposited to the north of the present Ouachitas could not have been thrust southward over Ouachita rocks during Caney time. However, the Caney boulders themselves are the only, and not very satisfying, evidence of this hypothetical southward overthrusting.

Dake⁵⁰ first suggested that "an enormous overthrust fault, the displacement measured in scores of miles—may have crowded the Ouachita facies from the south or southeast far to the northeast, over the Arbuckle facies. . . ." This theory has been considered by Honess⁵¹ in explaining the sources of the Ouachita asphalt deposits and by Powers⁵² and van der Gracht⁵³ in explaining the origin of the "Caney" boulders. Any theory of long-distance overthrusting must necessarily involve low-angle faults. Miser⁵⁴ has added credence to the view that great, low-angle faults exist in the Oklahoma Ouach-

⁵⁰ C. L. Dake, "The Problem of the St. Peter Sandstone," *Mo. School of Mines and Metallurgy Bull.*, Vol. VI, No. 1 (1921), p. 55.

⁵¹ "Geology of Atoka, Pushmataha, McCurtain, Bryan and Choctaw Counties (Oklahoma)," *Okla. Geol. Surv. Bull. 40-R* (1927), p. 26.

⁵² *Op. cit.*

⁵³ *Op. cit.*

⁵⁴ *Op. cit.*, p. 19.

itas by his map of the areal relations in the Potato Hills which suggest a fault window. The belt of supposed overthrust rocks which bounds the possible window on the northwest side of Potato Hills is so narrow (less than 3 miles in width) as to cast some doubt on the probability that a section from the top of the Atoka through the Caney, Jackfork, and into the Stanley formation (a thickness presumably greater than 2 miles) is concealed under it. The writer has drawn a structure section (Fig. 3) illustrating the grounds for this doubt. Other interpretations of the areal relations in the Potato Hills are explained below.

The Boktukola fault cuts across the Boktukola syncline in north-western McCurtain County. Miser⁵⁵ has attempted to measure horizontal displacement along the fault by measuring the displacement of presumably identical synclinal axes. It should be pointed out that two synclinal axes in their present positions on one side of the fault trace very nearly coincide with two others on the opposite side.

It may be unnecessary to postulate a hypothetical window⁵⁶ exposing older Paleozoic rocks in the Choctaw anticlinorium to explain an apparent lack of structural conformity within and outside of the supposed window. The older Paleozoic rocks are nearer a probably competent basement of pre-Cambrian rocks than are those of younger Paleozoic age, and folds are consequently more open with stratigraphic depth.

In the Arkansas Ouachitas the comparatively few faults are reported⁵⁷ to be thrusts of the broken-fold type, and there are probably many thrust faults in Oklahoma which are the result of the post-Boggy orogeny. In Oklahoma, however, there are many long faults which are subparallel to the grain of the country. Several extend the entire length of the mountains in Oklahoma from the coastal plain into western Arkansas. Since the time of Taff's⁵⁸ early work, these faults have been thought to be thrusts, although of high angle. Exposures of the surfaces of these faults have not been reported, and apparently have not been found.⁵⁹

⁵⁵ *Ibid.*, p. 20.

⁵⁷ *Ibid.*, p. 18.

⁵⁶ *Ibid.*, p. 22.

⁵⁸ *Op. cit.*

⁵⁹ In a letter dated September 8, 1930, Mr. Miser stated that he knew of no locality in Oklahoma showing the exposure of such a fault surface.

The apparently unanimous belief that these long faults are thrusts is largely based upon regional and, to a certain extent, upon local structural relations. (1) As the diastrophism which produced the long faults was undoubtedly great, it has generally been considered to have been a part of the major, post-Boggy orogeny, and hence is supposed to have produced the crustal shortening of thrust faults. (2) The upthrow sides of the long faults are on the south, that is, on the sides from which the direction of pressure is thought to have come during the major orogeny, as should be the case if the faults are thrusts resulting from that diastrophism. (3) The long faults are subparallel to the grain of the region, as should be expected of thrusts produced by the same forces which produced the grain.

These general relations support the belief that the long faults are thrusts, as does the following more specific relation. The relations along most of the long faults are not well known, because valley-forming Stanley shale crops out along almost the entire lengths of their upthrow sides which are on the south. The Jackfork sandstone or other rocks at most localities on the downthrow sides dip steeply (about 40° - 60°) southward toward the upthrow sides. These steep dips of the rocks on the downthrow sides toward the traces of the faults suggest that the faults are high-angle thrusts, although they do not preclude the possibility that the faults are normal.

The structural relations along the Choctaw fault, the longest of all, which crops out along the north-northwest border of the Oklahoma Ouachitas, are very different from, and are much better known than, the relations along the other long faults. Long and narrow outcrops of the Wapanucka limestone are cut off by this fault. This circumstance facilitates the study of the structural relations. The upthrow side of the fault is on the south, but on this side a steeper dip of about 60° away from the fault's trace usually prevails than the dip of about 30° - 40° , also away from the trace, on the north or downthrow side. These relations not only indicate that the fault is of high angle but also suggest that it may be normal, because if the fault were a thrust resulting from the breaking of an overturned fold the strata on the upthrow side should dip less steeply than the beds on the downthrow side, which in many localities might be expected to be overturned. In the quarry at Stringtown, strata of the String-

town formation dip steeply westward on the east or upthrow side of the Choctaw fault, and on the west side Atoka strata dip steeply westward. These relations also suggest normal faulting.

If one assumes that the long faults occurred at the time of the folding, he must conclude that they are thrusts, but if he assumes that they occurred during relaxation subsequent to folding or during some later period of tension, he may well conclude that the faults are normal. In considering the possibility that the long faults may be normal, the uniformity with which downthrow sides are on the north may be explained by the theory that faulting was down from and around the old positive or competent area, Llanoria, which lay to the south. Normal faults of many miles length are known which are subparallel to a pre-existing grain. It should be noted that Honess found a number of normal faults in McCurtain County, and one of them is the only fault⁶⁰ whose dip could be measured. Proof that the long faults are normal would add credence to Robinson's⁶¹ suggestion that there is a genetic relationship between them and the Balcones and Mexia fault zones of Texas. The Texas zones may have been faulted with downthrow sides away from Llanoria during the same epoch as were the long faults of the Oklahoma Ouachitas, and during post-Cretaceous time, after the cessation of the faulting in Oklahoma, additional displacements may have occurred along the older zones. In the case of the Mexia zone the downthrow was away from the still competent area which was the former positive element, Llanoria, but in the case of the Balcones zone the downthrow was dominantly away from the Central Mineral region of Texas, thus producing the graben between the Mexia zone on the southeast and the Balcones zone on the northwest. Possibly pre-Cretaceous Balcones and Mexia normal fault zones connected with the long faults in the Ouachita Mountains.

While the writer is far from being entirely convinced that the long faults are normal, the bulk of the evidence favors the conclusion that they are of high angle. In the absence of more positive evidence, the

⁶⁰ Honess, "Geology of the Southern Ouachita Mountains of Oklahoma," *Okla. Geol. Surv. Bull. XXXII*, Part I (1923), p. 241.

⁶¹ H. M. Robinson, "The Origin of the Structure of Northeast Texas Petroleum Area," *Econ. Geol.*, Vol. XVIII (1923), pp. 722-31, 726.

steep dips adjoining the traces of the faults indicate that the surfaces of the faults are likewise steeply inclined. Furthermore, these faults do not show the usual characteristics of low-angle, long-distance overthrusts. Windows, if present, are a criterion of low-angle thrusting, but they are much less common in regions which are known to have this type of faulting than are either outlying klippen or peninsula-re-entrant outcrop patterns of the overthrust masses, whether these patterns are of the dendritic type associated with a nearly plane fault surface or of the type associated with an undulatory surface as in the case of the Rome fault in Georgia. At no place along the several hundred miles of long fault outcrops do such phenomena occur. The lack of such evidence of low-angle faulting casts doubt upon the actuality of windows. If the surfaces of such hypothetical overthrust faults are thought to have been folded during or after thrusting, so that they dip steeply in most outcrops, surely in many places along anticlinal axes of the folded fault surfaces, these surfaces should be nearly horizontal, and should show peninsula-re-entrant outcrop patterns of the overthrust sheets.

BOULDER FACIES CONSIDERED AS NON-EXOTIC

Although older Paleozoic rocks in the "Caney" boulders are not like outcropping Ouachita rocks, but are more like Arbuckle rocks, boulders of younger Paleozoic age are composed of Ouachita rock. An explanation of the younger boulders does not require long-distance transportation, and the evidence afforded by some of them appears to preclude such transportation. The friable and soft shale boulders in the sandstone at Stapp could not have been transported far by any process which might have crushed or shattered them. Blocks of Caney shale in modern stream channels are either on or within a few hundred feet of an outcrop of the parent rock. A friable boulder of chert breccia found in southeastern Atoka County would probably have been shattered during any considerable transportation. The great masses, or boulders, of older Paleozoic rock in the shale in Johns Valley have probably not been transported any considerable distance. It is a reasonable assumption that all of the boulders have been derived from the same general source.

As no probable extraneous source of the boulders is known, the

Ouachita area itself should be considered as a possible source. All of the boulders may have been derived from local rocks, but the older Paleozoic, Arbuckle-like section does not crop out. The older Paleozoic Ouachita rocks in Oklahoma are confined in outcrop to McCurtain County and to the Potato Hills and Black Knob Ridge inliers. The Potato Hills are 30 miles northwest of the McCurtain County outcrop, and Black Knob Ridge is 40 miles west-southwest of the Potato Hills and 65 miles west-northwest of the McCurtain County area. Because of crustal shortening, these intervening distances are less than they were at the time of deposition of the exposed Carboniferous rocks. Because the only outcropping, older Paleozoic rocks in the Black Knob Ridge and Potato Hills inliers are similar to those in the McCurtain County area, it has been assumed in the past that rocks of the same facies underlie the intervening area.

Drill holes in this intervening area have not encountered rocks of greater age than Carboniferous, nor have pre-Carboniferous rocks been reached in wells to the southwest of it on the coastal plain in Oklahoma. Wells, however, drilled farther east, on the coastal plain in Oklahoma and adjacent Texas⁶² to the southwest of the McCurtain County inlier of pre-Carboniferous rocks, have penetrated older Paleozoic and Devonian rocks of the outcropping Ouachita facies. Other wells in the vicinity of Denison, Texas, 45 miles south-southwest of the west end of the Ouachitas, have penetrated similar pre-Carboniferous strata. But, in the heart of the Oklahoma Ouachitas there is a diamond-shaped area, under which the nature of the pre-Carboniferous rocks is not known. The area is 100 miles long by 40 miles in greatest width, the long axis of the diamond extending in an east-northeast direction.

There is some probability that Arbuckle-like, older Paleozoic rocks were deposited in part of this area. A well drilled on the west side of the area penetrated a normal section of Arbuckle rocks from "Carboniferous Caney shale down to the Ordovician Simpson formation"⁶³ after drilling through a thin veneer of Cretaceous. This

⁶² H. D. Miser and E. H. Sellards, "Pre-Cretaceous Rocks Found in Wells in Gulf Coastal Plain South of Ouachita Mountains," *Amer. Assoc. Petr. Geol.*, Vol. XV (1931) pp. 801-18.

⁶³ *Ibid.*, p. 808.

well (Hansen *et al.*, in the SE. $\frac{1}{4}$, NW. $\frac{1}{4}$, Sec. 17, T. 4 S., R. 11 E., Atoka County, Oklahoma) is located on the coastal plain, 10 miles south-southwest of Black Knob Ridge, about 2 miles east of the southwesterly projection of the strike line of the pre-Carboniferous rocks in the ridge. Thus, it appears to be located within the concealed Ouachitas near their west end.

A Trinity (Cretaceous) limestone conglomerate or breccia which crops out well within the critical area further suggests that Arbuckle-like, pre-Carboniferous rocks had been deposited nearby, and had outcrops in Cretaceous time which were the source of the limestone fragments. This conglomerate crops out (NE. cor., Sec. 5, T. 4 S., R. 14 E.) 4 miles west of Darwin in southeastern Atoka County, Oklahoma. This location is only a few miles south of several "Caney" shale boulder localities. Small (up to 3 cm.), angular to rounded, much-weathered, gray to buff limestone fragments are in a friable sandstone matrix. Caney boulders, whose horizons cropped out at the time of deposition of the conglomerate, were probably not an adequate source of the abundant limestone fragments. If the fragments had been derived from a monadnock in which Caney boulders cropped out, probably quartzitic Jackfork sandstone also would have been cropping out in the same erosional remnant, and fragments of this more resistant rock undoubtedly would have been more abundant than those from limestone boulders. There are Trinity limestones which are older than the conglomerate, but they are not present in the Cretaceous section⁶⁴ near this locality in which younger Trinity horizons overlap the truncated Paleozoics. The fragments in the limestone conglomerate were probably derived from a very near outcrop of Paleozoic limestone. It should be noted that this outcrop of the conglomerate is located only a short distance west of the projected axis of the syncline in the center of which Johns Valley is located.

If the rocks in the boulders are taken to represent a section, most of Hunton time is represented by a hiatus, and much of this recordless time also corresponds to hiatuses⁶⁵ in the Talihina chert. As the

⁶⁴ H. C. Vanderpool, "A Preliminary Study of the Trinity Group in Southwestern Arkansas, Southeastern Oklahoma, and Northern Texas," *Amer. Assoc. Petr. Geol. Bull.*, Vol. XII (1928), pp. 1069-94, Figs. 2 and 3.

⁶⁵ Ulrich, *op. cit.*, p. 30, Fig. 2.

four Hunton formations above the Chimneyhill in the Arbuckles are fossiliferous, it is probable that they are not represented in boulders or they would have been identified, and accordingly these formations were probably not present in the section of rocks from which the boulders were derived. Lower Simpson time also appears to be represented by hiatuses both in rocks in boulders and in outcropping Ouachita rocks. A correlation of these hiatuses suggests that the deposition area of the rocks which were the source of the older Paleozoic boulders had a physical history more comparable to the Ouachitas than to any other known area.

It is probable that Arbuckle-like rocks of older Paleozoic age underlie the Arkansas Valley in Oklahoma. It has been reported⁶⁶ that a well (Pattison and Phillips, McDuff farm, Cen. NW. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 32, T. 9 N., R. 16 E., Pittsburg County, Oklahoma), located about 20 miles north of the Ouachitas, encountered probable Viola limestone at a depth of 5,268 feet. Ulrich⁶⁷ has postulated a "former topographic boundary" along the northwest side of the Ouachitas between Ouachita rocks and Arbuckle-like rocks. As rocks of younger Paleozoic age like those which crop out along the north side of the Ouachitas were the source of many boulders, it is probable that older Paleozoics from, or near, the same region were the source of others. Rocks like the Middle Devonian cherty beds on Brushy Creek are known from nowhere else in Oklahoma except at this Ouachita locality.

BENGALIA, THE LAND AREA WITHIN THE OUACHITAS

A logical theory is required to explain how an older Paleozoic, Arbuckle-like section of rocks might have been deposited in the diamond-shaped area between McCurtain County and the Potato Hills and Black Knob Ridge.

There is evidence⁶⁸ that land existed along the north side of the Ouachita area in Arkansas during several periods of pre-Stanley Paleozoic time, and hiatuses in the section of this age which is ex-

⁶⁶ W. W. Clawson, Jr., "Oil and Gas Geology of Coal and Pittsburg Counties (Oklahoma)," *Okla. Geol. Surv. Bull.* 40-JJ (1928), p. 15.

⁶⁷ *Op. cit.*, p. 26.

⁶⁸ H. D. Miser and A. H. Purdue, *U.S. Geol. Surv. Geol. Atlas, Hot Springs Folio No. 215* (1923); "Geology of the De Queen and Caddo Cap Quadrangles, Arkansas," *U.S. Geol. Surv. Bull.* 808 (1929), p. 44.

posed in the Potato Hills and Black Knob Ridge indicate that there were land areas along the north side of the Oklahoma Ouachitas. At times this land, for which the name "Bengalia" is here proposed, was composed of a few low islands, whereas during other periods it formed a continuous low barrier which may have connected with Llanoria, the land to the south. Early in the Paleozoic, pre-Cambrian rocks were exposed on Bengalia, and later, as a result of changes in the positions of land and sea areas, younger rocks formed the land. Bengalia probably tended to retain its position along the north side of the Ouachita area, because of the tendency of a basin of deposition to retain synclinal structure when warped by tangential pressure.⁶⁹ The central basin, however, was probably land at various times, as testified by hiatuses revealed by the rocks in the "Caney" boulders.

In pre-Stanley time streams from Llanoria and Bengalia transported colloidal silica to the sea, where it was precipitated near shore. For long periods of time the lands were so low that the seas were clear and allowed the deposition of relatively pure bedded cherts, although pre-Stanley shales and sandstones aggregate at least twice the thickness of the chert beds. As silica⁷⁰ is evidently precipitated almost immediately upon entering the sea, such chert beds were deposited very near the lands and probably do not underlie all of the central area between Llanoria and Bengalia. In this area, which evidently connected with the Arbuckle sea by way of a strait south of Black Knob Ridge, Arbuckle-like rocks were deposited. Older Paleozoic Bengalia lands were probably located to the east of the Potato Hills and Black Knob Ridge inliers. In Arkansas (novaculite) time Bengalia probably extended most of the length of the Ouachitas. The intervening area between Bengalia and Llanoria was so narrow in Arkansas during pre-Stanley time that the chert facies covered the basin.

Bengalia, with Llanoria, probably had its climax as a land area during post-Arkansas (novaculite) pre-Caney (Mississippian) time. Llanoria became high and supplied most of the clastic material for the Stanley-Jackfork succession, and Bengalia rose and formed a low

⁶⁹ Bailey Willis, "Mechanics of Appalachian Structure," *U.S. Geol. Surv., 13th Ann. Rept.*, Part II (1893), pp. 217-81, 262.

⁷⁰ W. H. Twenhofel, *Treatise on Sedimentation* (Baltimore, 1926), p. 383.

barrier on the north side of the filter-basin-like trough which received the sediments. Bengalia extended far to the south and east so that a thick Stanley-Jackfork succession was confined to the narrow trough at the same time that only a few hundred feet of lower Caney shale were deposited to the north and west of the barrier. Arbuckle-like rocks as well as strata of the chert facies cropped out in Bengalia. In the west end of the Ouachitas a land area of tilted Arbuckle-like rocks extended along the axis of the Johns Valley syncline, rising above the floor of the basin. The rocks in the Potato Hills area had been warped into a gentle dome which had collapsed with normal faulting before Stanley deposition. As the sea encroached upon this low area, the Stanley shales, sandstones, and chert conglomerate⁷¹ were deposited between islands of older rocks. The areal distribution of rocks in the Potato Hills may also be explained by the fault-window theory,⁷² which has already been discussed, or by the theory of the collapse of a dome with normal faulting subsequent to post-Boggy folding of the Ouachitas, but the evidence of land during Stanley time, as testified by the chert conglomerate, favors the theory of pre-Stanley warping and normal faulting. Typical conglomerates are relatively rare in the sediments deposited along the shores of Bengalia probably because the land was low and streams were short.

BOULDERS FROM BENGALIA

By later Caney (Johns Valley) time Llanoria had been eroded lower and Bengalia was a chain of islands with many straits which connected the Ouachita basin with the sea to the north and west. Caney shale was deposited in the north side of the basin and continued to be deposited to the north and west of Bengalia. Nearer Llanoria, in the basin in Arkansas and in the south side of the basin in Oklahoma, coarser clastics continued to be deposited throughout Caney and into Atoka time.

Early in this Johns Valley epoch of Caney time, the Ouachita basin in Oklahoma began to sink, probably accompanied by normal faulting along the south side of the Bengalia islands. The strata exposed in Bengalia had already been warped, faulted, and eroded in

⁷¹ Powers, *op. cit.*, p. 1039.

⁷² Miser, *op. cit.*, p. 20.

several preceding periods so that rocks ranging in age from Ordovician to Mississippian (about 6,000 feet of section) were exposed.

Miser and Purdue⁷³ have noted that the Blaylock sandstone (Silurian) and older rocks in Arkansas are more crumpled than the overlying strata. Perhaps this deformation is the record of the first diastrophism which warped Bengalia, but later movements in Devonian, and especially in early Mississippian, time largely contributed to the exposure of this section of rocks. At the contact between the Arkansas novaculite (dip 73°) and the Atoka (dip 55°), 1 mile west of Bengal, the chert dips 18° more steeply than does the younger Atoka shale.

Earth tremors accompanying the downwarping of the basin, or other causes, may have produced subaerial and submarine landslips of fragments of Bengalia rocks into the Caney shale then being deposited. Subaerial processes had probably transported many of the smaller fragments into or near the sea, but submarine landslips probably were responsible for the wider distribution of these "Caney" boulders. Submarine landslips have been postulated as a process capable of transporting large masses of rock,⁷⁴ but, because such modern slips occur in the sea, distance of carriage and size of blocks transported have not been determined. Mud flowage⁷⁵ is the subaerial process probably most nearly analogous to submarine land slippage. Mudflows have been observed to carry great rock fragments down relatively gentle slopes. Subaerial mudflows, however, cease to move after becoming too viscous from the loss of water, and must dam up and absorb more water before they can flow again.

Submarine mudflows resulting from landslips, having abundant water, would probably flow continuously until a very low angle of rest (perhaps as low as 2° or 3°) is reached. Five houses which slipped into Lake Limon⁷⁶ at Zoug, Switzerland, on July 5, 1887, came to rest

⁷³ Miser and Purdue, "Geology of the De Queen and Caddo Cap Quadrangles, Arkansas," *op. cit.*, p. 44.

⁷⁴ E. B. Bailey, L. W. Collet, and R. M. Field, "Paleozoic Submarine Landslips near Quebec City," *Jour. Geol.*, Vol. XXXVI (1928), pp. 577-614.

⁷⁵ Sir W. M. Conway, "Exploration in the Mustagh Mountains," *Geog. Jour.*, Vol. II (1893), pp. 280-303, 291.

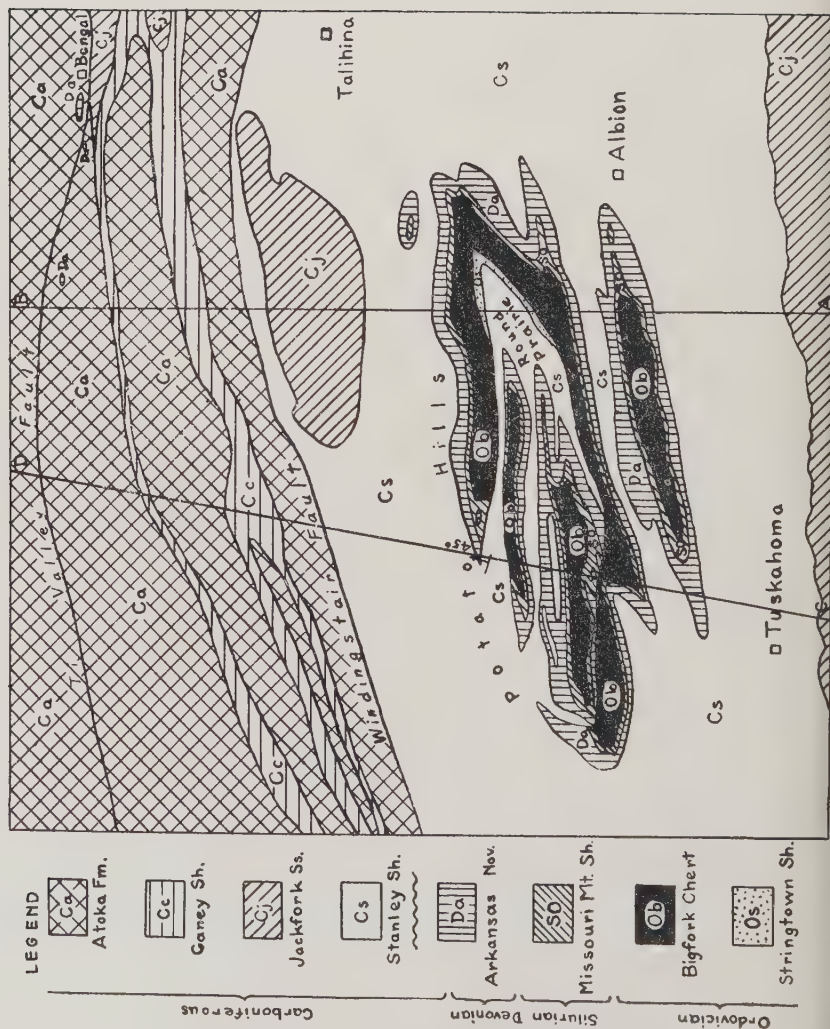
E. Blackwelder, "Mudflow as a Geologic Agent in Semi-arid Mountains," *Geol. Soc Amer. Bull.*, Vol. XXXIX (1928), pp. 465-84.

⁷⁶ L. W. Collet, *Les Lacs* (1925), p. 194.

at a depth of 45 meters at a distance of 1,020 meters from, and about $2\frac{1}{2}^\circ$ below, the point of departure. It is conceivable that in a flow of considerable magnitude even huge masses of rock might be transported several miles.

An outlying Bengalia island located in the Johns Valley area may well have been the source of the immense Caney boulders in that locality. The blocks are of such great dimensions that it is improbable that any ordinary sedimentary process has transported them far, and there is no evidence that they were tectonically transported. The Arbuckle-like rocks projected up through the partially overlapping Stanley and Jackfork until buried by upper Caney and Atocha strata. On first thought it would seem that the highest point on the island must have had an elevation about 12,000 feet above the floor of the basin in which these two thick formations were deposited. But it is more probable that the measured thicknesses of these formations are only apparent and not true, and that nowhere was the Stanley-Jackfork succession deposited in a thickness greater than a fourth to a half of the measured thickness of these strata. The Ouachita trough probably had an uneven floor with minor depressions and elevations upon it. The Stanley-Jackfork sediments were laid down with depositional dips into the depressions and away from the elevations. When the area was subsequently folded, the sediments in the minor basins of deposition became synclinoria and those on the elevations became anticlinoria.

Sediments preserved in one of these gently folded synclines afford the best section for measuring apparent thickness. The Bengalia island in the Johns Valley locality need not have had an elevation of more than 3,000-4,000 feet above the lowest point on the floor of the major basin. The island was probably a detail rising above the floor of one of the secondary basins and caused depositional dip away from it only over a minor area. For this reason, the buried hill, at the time of diastrophism, only determined the location of the center of the syncline instead of the position of an anticline. Had the buried hill been of considerable length, and elongated approximately at right angles to the direction of compression, it probably would have determined the location of an anticline, but if the hill was long and elongated approximately parallel to the direction of pressure, it probably would have buttressed the strata and determined the posi-



a) Map showing areal relations (after Miser). (SO includes Missouri moun-



FIG. 3.—Geologic map and structure sections of the Potato Hills and adjacent areas in southeastern Oklahoma

c) Structure section along line, C-D, based on the fault-window theory, showing a minimum thickness of strata which must be covered by the narrow belt of supposed overthrust rocks on the northwest side of the Potato Hills. This thickness is so great that Jackfork sandstone should crop out within the window. If the strata have undulatory structure and if the Atoka formation is partially repeated under this part of the supposed overthrust sheet, the covering would by no means be wide enough to conceal the section from Stanley to Atoka.

d) Structure section along line, C-D, based on the theory of Stanley overlap subsequent to post-Arkansas (novaculite) doming and faulting.

e) Structure section along line, A-B, based on the theory of Stanley overlap subsequent to post-Arkansas (novaculite) doming and faulting.

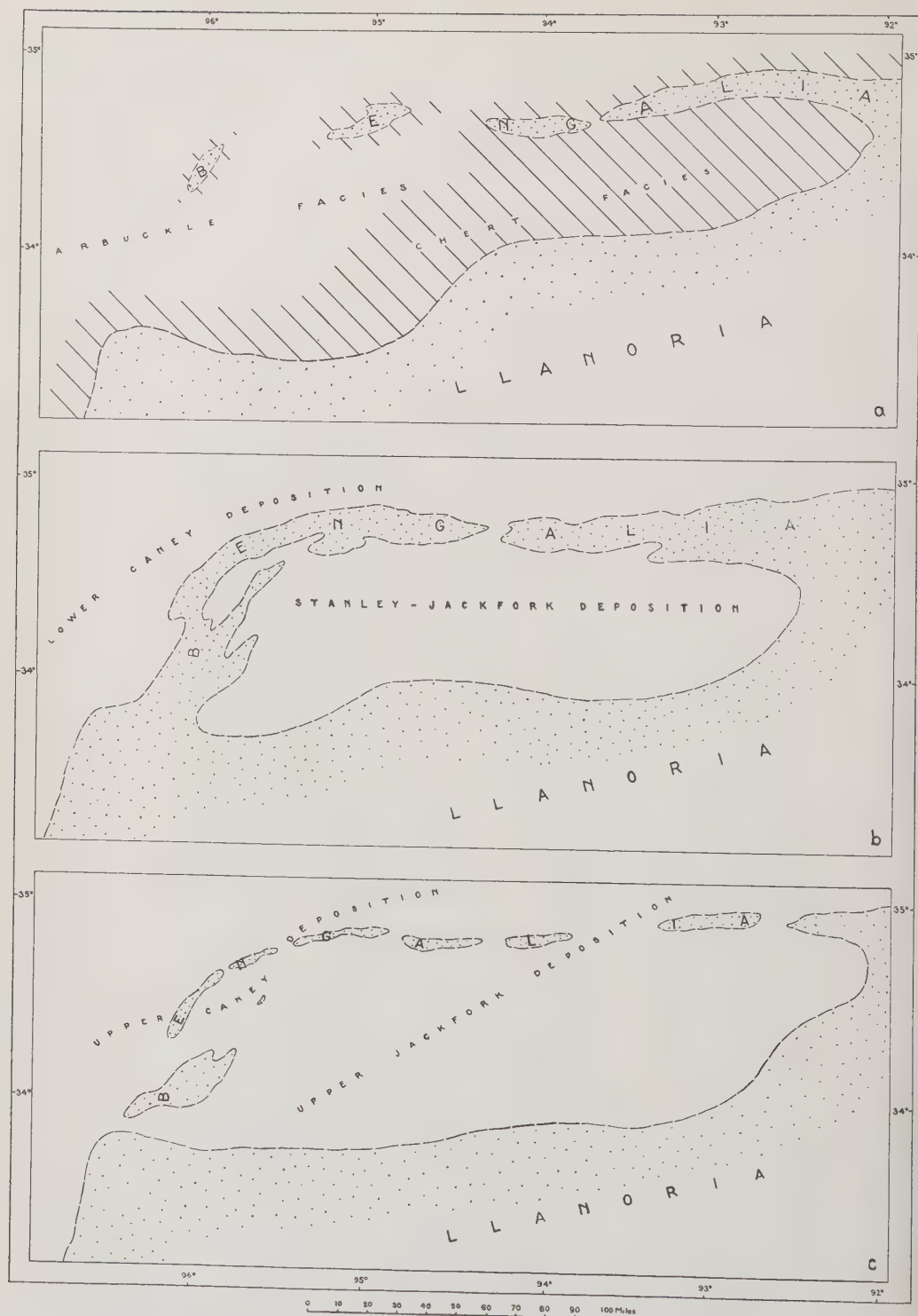


FIG. 4.—Paleogeographic maps of the Ouachita region during Paleozoic time. *a*, Ordovician; *b*, Stanley-Jackfork, or early Caney (Mississippian); *c*, Johns Valley epoch of later Caney (Mississippian and Pennsylvanian).

tion of a syncline. In this position the buried hill would have caused upwarping of the strata at the end nearer the direction from which pressure was transmitted, by resisting pressure, and in transmitting pressure would have caused the strata, at the opposite end to buckle into a probably arcuate, anticlinal fold. The writer performed pressure-box experiments with a number of buried-hill models, some of which are illustrated in Figure 6. Conclusions regarding the effects of variously oriented, buried hills in locating anticlines and synclines in folded strata are taken from these experiments.

Boulders of more than 30 feet in greatest dimension are not known outside of Johns Valley, perhaps because most of the outcrops of

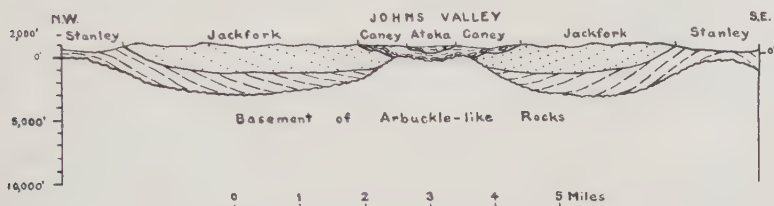


FIG. 5.—Structure section across Johns Valley from northwest to southeast (from S.E. cor., Sec. 14, T.1 N., R. 15 E., to S.E. cor. Sec. 17, T.1 S., R. 17 E.).

boulder horizons are farther seaward from the sources of rock fragments, or possibly represent boulders which flowed down gentler slopes, or were farther from earthquake centers, and flowed as the result of less intense tremors.

The inliers of pre-Stanley rocks (Black Knob Ridge, Wesley, Brushy Creek, 7 miles south of Hartshorne, and the two west of Bengal) within the Atoka belt on the north-northwest side of the mountains are approximately on the axis of Bengalia as it existed from Johns Valley Caney time to early Atoka time. The chert rocks, being better ridge-makers than the Arbuckle-like rocks, maintained higher elevation, and composed the higher areas of Bengalia which were last to be overlapped and which form the only present-day inliers of the former land. The main belt of boulder-horizon outcrops is a few miles south of this probable axis. Of the six known inliers of "Caney" strata along the axis—at Wesley, Brushy Creek, 2 miles northeast of Ti, two localities southeast of Recyl, and 8 miles east of Bengal—the three last mentioned contain boulder horizons. As

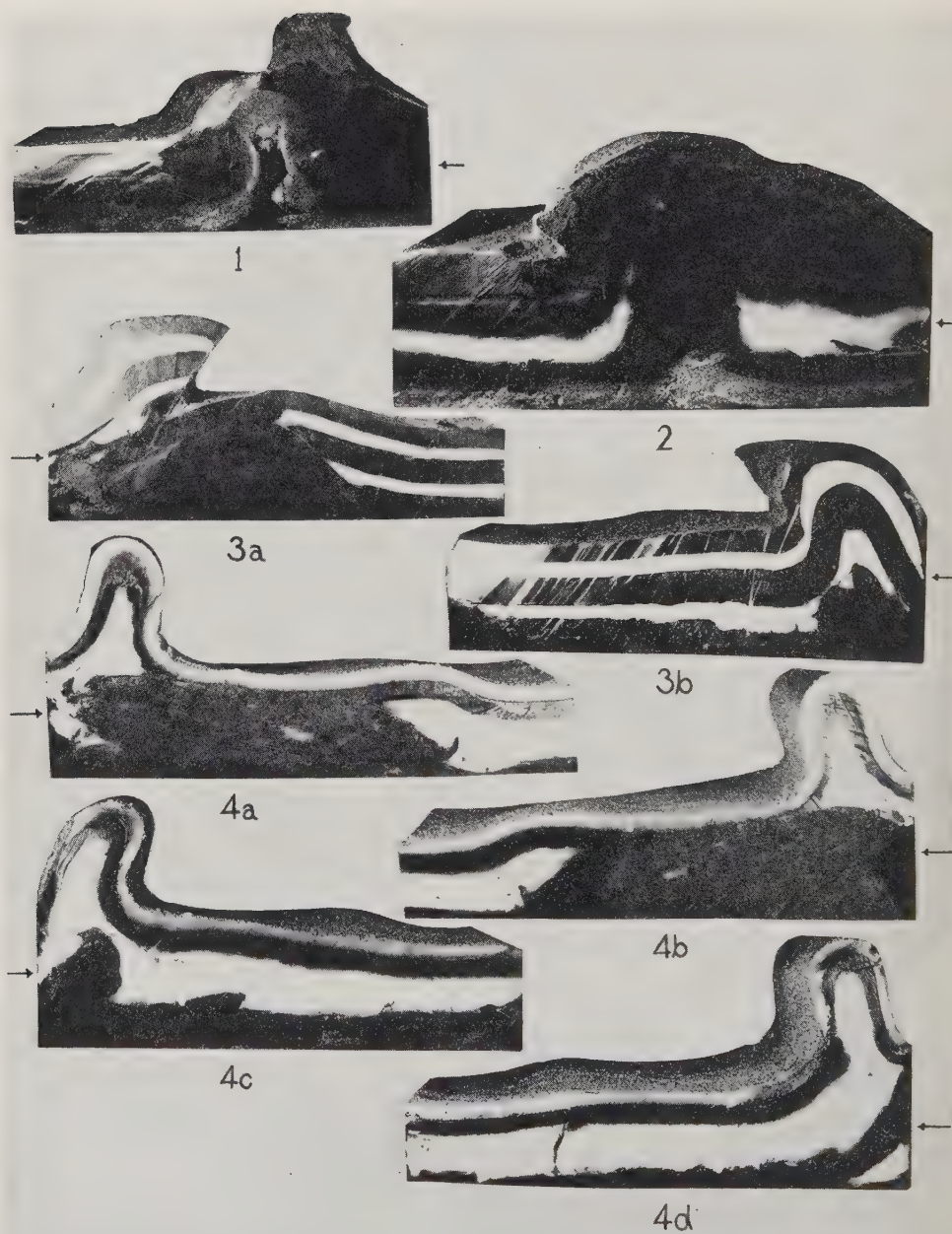


Figure 6

FIG. 6.—(legend on opposite page)

the horizons are not continuous as boulder beds, and as the areas of outcrop are small, three boulder-horizon outcrops in the six inliers are as many as might be expected.

Boulders were apparently not deposited in the Caney shale on the north side of Bengalia probably because the sea floor sloped gently northward from the land in that direction, and was less disturbed by crustal movements.

Boulders continued to be deposited intermittently from late Mississippian into early Pennsylvanian time when most of the remaining Bengalia islands were overlapped by Atoka strata. Perhaps Black Knob Ridge, which may have been rejuvenated by an early Pennsylvanian uplift,⁷⁷ was the last Bengalia island to stand above the transgressing sea; for there are conglomerates of Talihina chert and Stringtown shale fragments in the Atoka, Hartshorne, McAlester, Savanna, and Boggy formations a few miles to the north and west of this inlier.

Some time during the interval between Boggy and early Cretaceous time⁷⁸ the strata of the Ouachita area were folded and faulted and subsequently truncated. Post-Cretaceous erosion has sculptured the region into the Ouachita Mountains of today.

⁷⁷ Powers, *op. cit.*, p. 1048.

⁷⁸ Miser, *op. cit.*, p. 27.

FIG. 6.—Buried-hill models compressed in a pressure box. Models were 15 inches long by 8 inches wide, and were shortened to 10 inches. A mixture of half-paraffin and half-vaseline was used in the layers.

1. Longitudinal section showing a hill of sand at right angles to the direction of pressure which determined the position of the anticline.
2. Longitudinal section showing a hill of paraffin-vaseline at right angles to the direction of pressure which determined the position of the anticline.
3. *a-b*, Longitudinal section and the side view of a model having a paraffin-vaseline buried hill 7 inches long with a crest 1 inch high. Faulting occurred at the end of the hill toward the direction of pressure, and the hill was shortened and thickened, but pressure was transmitted, and a slight anticlinal flexure was produced at the opposite end of the hill.
4. *a-b*, Views of a longitudinal section. *c-d*, Side views. Dimensions of the hill are the same as in 3, but the bottom layer and the hill were modeled from sand saturated with the wax. An anticline developed at the end of the hill nearer the direction of pressure, and the hill transmitted pressure which caused an arcuate anticlinal flexure to develop at the opposite end.

